Advanced Materials Research Vols. 133-134 (2010) pp 653-658

doi:10.4028/www.scientific.net/AMR.133-134.653

Seismic Safety Assessment of the "Tekyeh Amir Chakhmagh" by Simplified Kinematic Limit Analysis

PASHANEJATI Seyed Rohollah[1,a] and MOLINS Climent[2,b]

[1]Astan quds Astan Quds Razavi consulting engineers, Tehran, Iran

[2] Departament d'Enginyeria de la Construcció. Universitat Politècnica de Catalunya, Barcelona, Spain

[a]pashanejati@gmail.com, [b]climent.molins@upc.edu

Abstract: This paper presents an investigation about the capabilities of simplified kinematic limit analysis for the safety evaluation and for the design of strengthening of masonry historical buildings. Limit analysis allows, with a reduced number of mechanical properties and for a given ultimate condition of the structure, affordable safety analysis and design of strengthening to the practitioners.

Masonry buildings subjected to earthquake show in most cases local failure mechanisms rather than global failure mechanisms due to the lack of integrity of structure. For this reason, simplified kinematic limit analysis has been accepted as a method to design the strengthening of masonry buildings, according to the Italian Ordinance (O.P.C.M. 3431).
To validate the applicability of this method, its results had been compared with those provided by three dimensional macro block limit analysis (Bustamante, 2003) for the Via Arizzi house. It is worth noting that results of simplified kinematic limit analysis provided similar results as those achieved by 3D macro block.

Also this method was implemented to seismic safety assessment of Tekyeh Amir Chakhmagh in Iran based on the results obtained for the out of plane and in plane behaviour of walls.
Tekyeh Amir Chakhmagh is an early 19th century tiled edifice that was built to serve as grand-stand for watching religious rites and also provided an imposing entrance to Amir Chakhmagh bazaar. This stunning three-story facade of the building is one of the most recognizable and unusual buildings in Iran.

Keywords: Seismic safety, simplified limit analysis, historical construction, Amir Chakhmagh

Introduction

Iran has an amazing heritage from ancient civilizations with more than 11000 monuments and historical constructions. Yazd, one of the Iranian cities comprising many ancient buildings, is located in the eastern part of central Iran situated on the high, desert plateau that forms much of the country. Amidst the immense desert, Yazd retains its sterling of old in religion, traditions and architecture and for this reason this city recognized by UNESCO as holding one of the oldest architecture all over the world(Iranchamber, 2008).

One of the precious buildings in Yazd is Tekyeh Amir-Chakhmagh. Although more often described as the entrance to a bazaar (see Fig. 1), the chief function of this building, known as a Tekyeh(a kind of place for doing religious rites), and the square before it is to host the Taziyeh, a cycle of passion plays commemorating the martyrdom of the third Imam, Hussein(A.S), which take place once a year during the mourning month of Moharram (Iranchamber 2008).

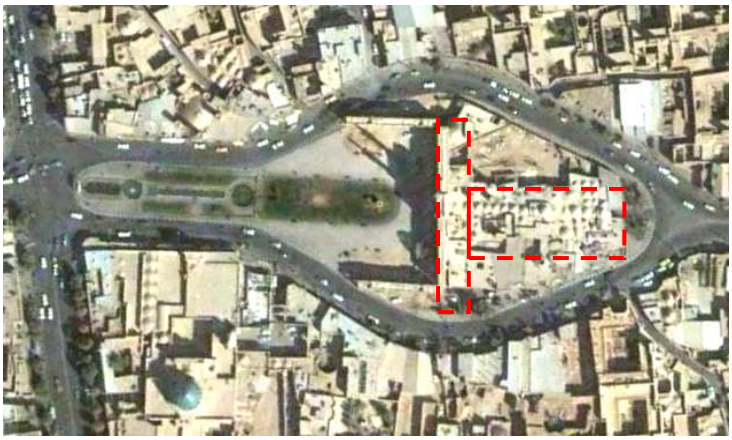


Figure 1: Bazzar and Tekyeh Amir Chakhmagh (photo by Google Earth 2009)

The site dates from the fifteenth century and was promoted by its eponymous builder, Amir Jalal Al-Din Chakhmagh, one of the Shahrokh Teymuri's commanders and governor of Yard. However, what remains to be seen today is this nineteenth century tiled portal, built as a grandstand from which the plays could be watched (Iranchamber 2008) and normally governor and his families have been cited in highest chamber of this façade to watch Taziyeh.

This stunning three-story facade of the Tekyeh which is overhung by two giant turrets (Yassavoli 2001), is one of the most recognizable and unusual buildings in Iran (Iraniantours 2008). The twin minarets and entire façade which is decorated with glazed tiles and plaster stalactite vaulting as it shown in Fig. 2 (Yassavoli 2001).

Clay brick and lime mortar are the constitutive materials of this building. Approximately, length, height and width dimension of it are around 65.0, 39.0 and 5.5 meter respectively. Fig. 3 shows the drawings of the plan and the front views and a section of Tekyeh Amir Chakhmagh.

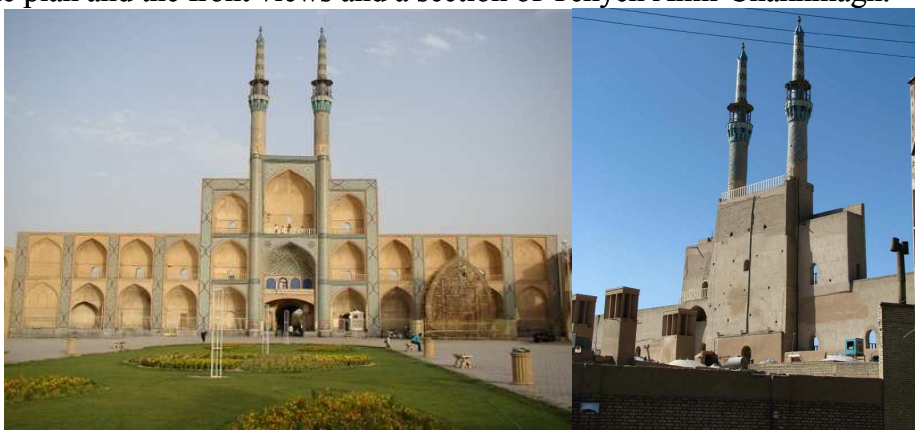


Figure 2: Tekyeh Amir Chakhmagh Façade and Backside

In the past and recent history several devastating earthquakes have occurred in Iran. So that, the stability of these ancient constructions during seismic events is of much concern. The study of the Tekyeh Amir Chakhmagh by applying simplified kinematic limit analysis is a contribution to the preservation of this heritage.

Simplified Kinematic Limit Analysis

The complex geometry of historical construction, the variability of properties of material and the lack of appropriate codes make the analysis of these ancient structures very challenging (Lourenco 2005). In this case, limit analysis is great tool for estimation of the ultimate capacity and for designing the strengthening requirements of these historical masonry structures due to the simplicity of its assumptions, the reduced number of necessary mechanical properties and the time analysis saving.

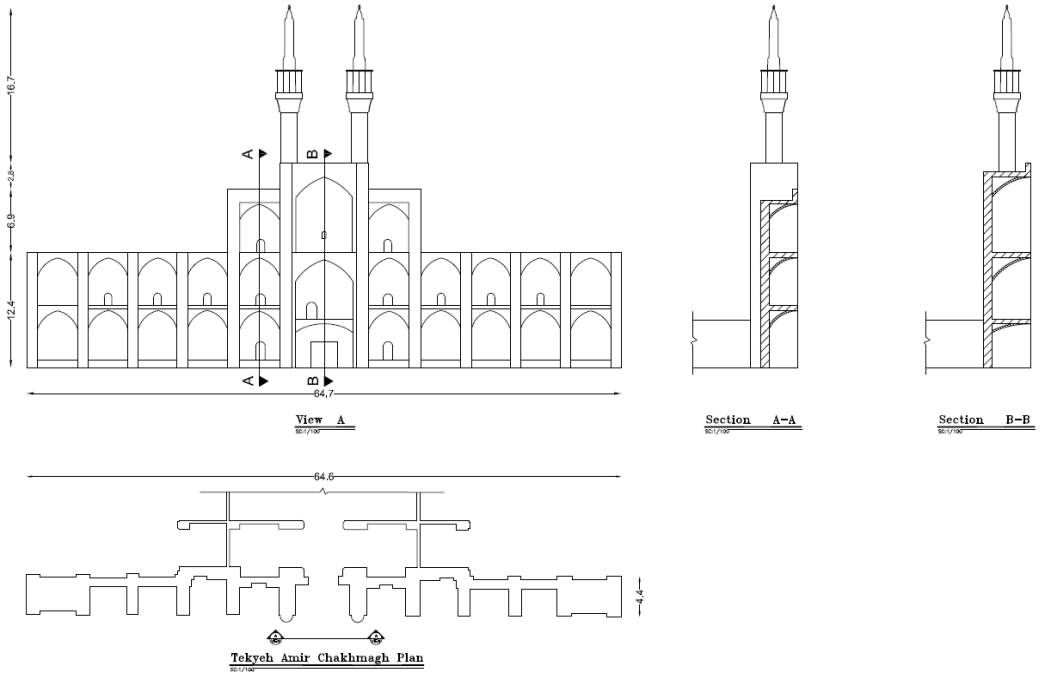
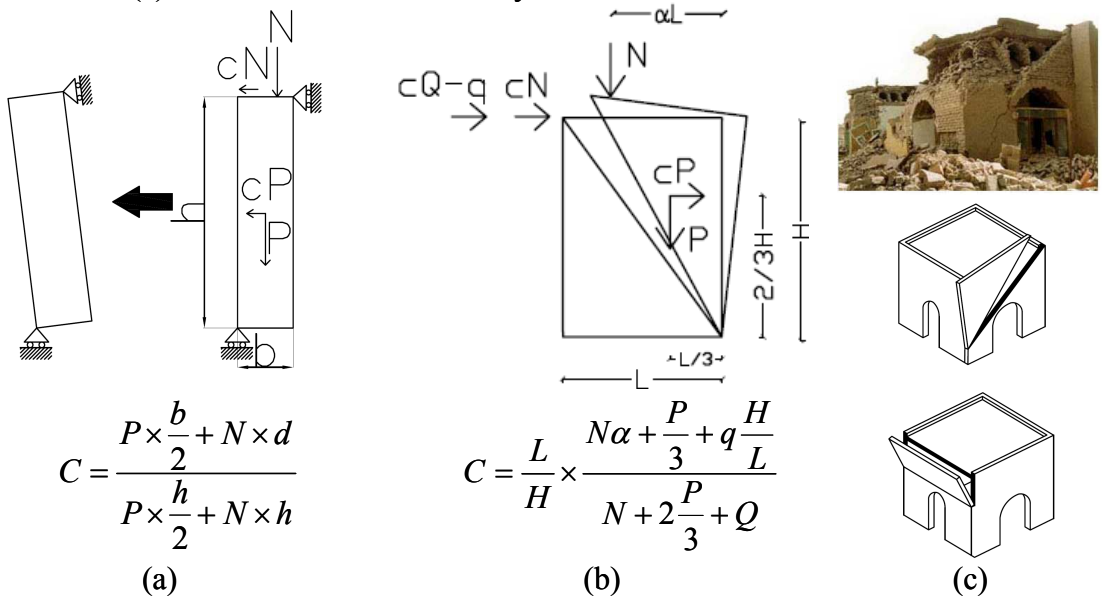


Figure 3: Plan (ICHODOC 2002), front view and Section of Tekyeh Amir Chakhmagh

Simplified kinematic limit analysis of a structure includes a series of limit analysis that check the stability of different specific failure mechanisms involving the equilibrium of macro-elements. This kind of analysis stemed from the fact that structural masonry constructions normally collapse due to a local failure mechanism. This idea leads to the use of simply kinematic models that can take into account the type of connection among the structural elements in two way, namely, linear kinematic analysis and nonlinear kinematic limit analysis in order to assess the seismic safety of masonry building in O.P.C.M. 3431. In this method, a collapse coefficient c=a/g is calculated, corresponding to the seismic masses multiplier characterizing the limit of the equilibrium conditions for the considered mechanism by kinematic models (Binda et al. 2006). Such studies, in comparison with standard assessment, showed better agreement with the poor structural properties normally detected in existing masonry buildings, (Valluzzi et al. 2004). Fig. 4 illustrates two kinematic models and the related collapse coefficients(c) which are used in this study.



$$C = \frac{P \times \frac{b}{2} + N \times d}{P \times \frac{h}{2} + N \times h} \qquad C = \frac{L}{H} \times \frac{N\alpha + \frac{P}{3} + q\frac{H}{L}}{N + 2\frac{P}{3} + Q}$$

(a) (b) (c)

Figure 4: Kinematics models for: a) out-of-plane(Avorio et al. 2002), b) in-plane overturning, of a solid wall simply supported to roof (Giuffrè 1993), c) occurrence of mechanism a & b in Bam earthquake.

In order to check the capacity of simplified kinematic limit analysis to asses the resistance of masonry structures, Table 1 (Pashanejati 2008) shows the outcomes of a 3D rigid macro block analysis performed by Bustamante (2003) and the simplified kinematic limit analysis of the Via Arizzi house before and after strengthening. Failure mechanisms for the house subjected to earthquake in both X and Y directions involve the overturning of the outmost wall and the safety factors are sensibly lesser than the required seismic coefficient.

In order to improve the seismic capacity of the building, the following strengthening measures were proposed (Benedictis et al. 1991). The construction of a reinforced concrete tie beam using embedded steel bars at the top of the walls and also the installation of two steel tie elements in X direction and three in Y direction at floor level were proposed.

The result revealed the acceptable accuracy of kinematic limit analysis also in terms of the designing strengthening.

It must be stressed that kinematic limit analysis is based on these assumptions; first, tensile strength is negligible due to the weakness of mortar and bond behaviour between mortar and brick, especially in ancient masonry. Second, probability of crushing failure can be neglected because in historical masonry structures the compressive stresses are usually small compared with the corresponding strength (in other words, masonry has an infinite compressive strength). And, finally, failure occurs under small displacements.

Walls in direction	*Before strengthening*			*After strengthening*		
	Rigid Macro block analysis	*Simplified kinematic limit analysis*		*Rigid Macro block analysis*	*Simplified kinematic limit analysis*	
X	0.05	0.046	8%	0.38	0.31	18%
Y	0.068	0.054	20%	0.28	0.30	7%

Table 1: Collapse Coefficient of Via Arizzi house (Bustamante 2003, Pashanejati 2008)

On the bases of above assumptions, 16 overturning and 13 in plane collapse mechanisms were devised and analyzed for seismic safety assessment of structure. These mechanisms are shown in Fig. 5.

According to the O.P.C.M. 3431 safety of each mechanism is verified in the linear simplified kinematic approach for ultimate limit state (ULS), if the spectral acceleration (a_0^*) that activates the failure mechanisms satisfies the following inequality:

$$a_0^* \geq \frac{a_g S}{q}\left(1+1.5\frac{Z}{H}\right) \quad (1)$$

Where ag is design acceleration of site, S is the soil factor which takes into account the stratigraphic profile of the soil foundation, q is the behaviour factor, Z is the height from the building foundation to the center of gravity of weight forces and H is the total height of the building from the foundation.

In this case the project is located on a site with soil class II according to Iranian code (Standard No.2800-84 2005) corresponds to the Class B. of Italian Code. S=1.0 were considered in the study according to the Iranian code (Standard No.2800-84 2005). Moreover ag=0.25 for City of Yazd according to the seismic macrozonation hazard map of Iran (Standard No.2800-84 2005) and the lateral loads resisting system consists of unreinforced masonry structures (q=1.25) (ISRM-85 2006) .

Volumetric weight of masonry material is considered 1850 kg/m3 (INBC-06 1996) and for sake of safety and lack of deep investigation no connection was considered between the walls and roofs.

Base on this explanation the collapse coefficient (c) and seismic safety verification of each mechanism is calculated by application of linear simplified kinematic limit analysis approach (O.P.C.M. 3431). The outcomes are presented in Table 2.

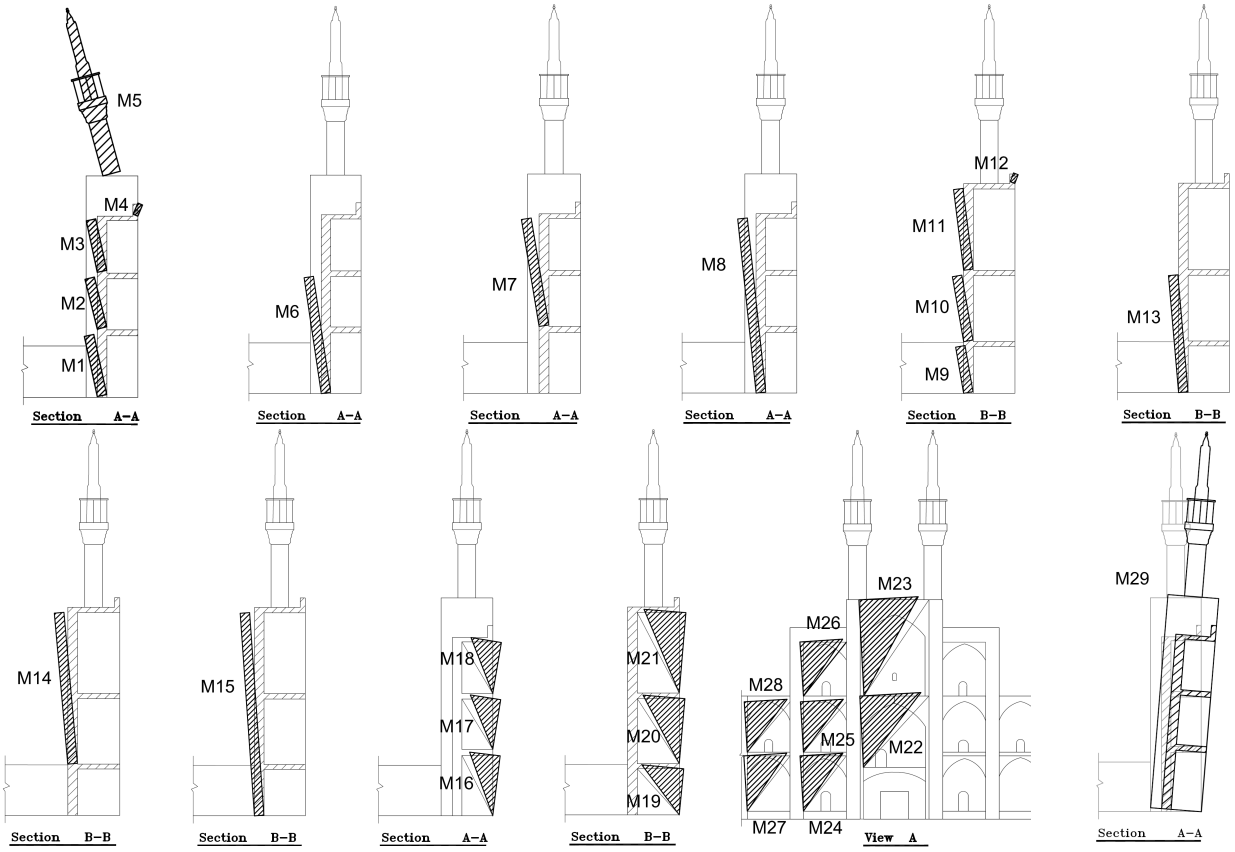


Figure 5: Overturning and In Plane Collapse Mechanisms of Tekyeh Amir Chakhmagh

Table 2: Seismic verification of different failure mechanisms

Failure Mechanism No.	*Collapse Coefficient (a/g)*	*Demand* $\frac{a_g S}{q}\left(1+1.5\frac{Z}{H}\right)$	*Capacity* a_0^* / g	*Failure Mechanism No.*	*Collapse Coefficient(a/g)*	*Demand* $\frac{a_g S}{q}\left(1+1.5\frac{Z}{H}\right)$	*Capacity* a_0^* / g
M1	0.09	0.24	0.15	M16	0.36	0.35	0.37
M2	0.12	0.33	0.23	M17	0.43	0.75	0.44
M3	0.18	0.4	0.18	M18	0.37	1.06	0.38
M4	0.42	0.45	0.42	M19	0.52	0.35	0.52
M5	0.1	0.43	0.1	M20	0.36	0.58	0.36
M6	0.06	0.28	0.14	M21	0.24	0.8	0.25
M7	0.08	0.37	0.08	M22	0.38	0.58	0.39
M8	0.05	0.32	0.05	M23	0.25	0.8	0.26
M9	0.11	0.23	0.16	M24	0.28	0.35	0.28
M10	0.09	0.32	0.17	M25	0.33	0.75	0.33
M11	0.12	0.42	0.12	M26	0.27	1.06	0.28
M12	0.56	0.49	0.56	M27	0.27	0.35	0.27
M13	0.06	0.28	0.12	M28	0.27	0.75	0.28
M14	0.06	0.38	0.06	M29	0.34	0.27	0.34
M15	0.05	0.34	0.05				

The results demonstrate that around 85% of failure mechanisms do not satisfy the Eq. 1 and it means that collapse will happen during the earthquake in Tekyeh Amir Chakhmagh structure. Despite this study is not based on a deep investigation of the construction, the huge difference between the demand and the capacity of the structure confirms that this stunning three-story façade is very

vulnerable to earthquake. Therefore, a deep investigation including both geometric and material survey and the definition of the strengthening needs are necessary to design an appropriate strengthening intervention to provide endurance to this historical construction.

Conclusion

The capacity of the simplified kinematic limit analysis to assess the seismic resistance of masonry structures and the effectiveness of its strengthening has been appraised with the example of Via Arizzi house, which has been studied by several authors.

In the case of Tekyeh Amir Chakhmagh, the analyses showed the weak seismic behaviour of this stunning three-story façade by collapsing of around 85% of the devised failure mechanisms, when acting the design base acceleration (DBE) level of Yazd city. From that result, it was concluded that the structure is not safe and also the large difference between demand and capacity of different failure mechanisms confirms that doing deep investigation and strengthening designing is necessary to save this precious building.

References

[1] (2002) The Iranian cultural heritage organization- documentation centre website. [Online]. Available: http://www.ichodoc.ir/

[2] (2008) The Iran chamber society website. [Online]. Available: http://www. iranchamber.com/

[3] (2008) The Iraniantours website. [Online]. Available: http://www. Iraniantours.com/

[4] Avorio, A, Borri, A, and Corradi, M (2002). "Per la ricostruzione. Iniziative di carattere tecnico e scientifico a supporto della ricostruzione," Roma: Regione dell'Umbria, DEI.. (In Italian)

[5] Benedictis, R, Felice, G and Giuffr`e, A (1991). Safety and Conservation of Historical Centres: The Ortigia Case, Chapter 9 Seismic Retrofit of a Building, pp. 189–217. A. Giuffr`e, Editori Laterza. (In Italian)

[6] Binda, L, Cardani, G, Saisi, A, and Valluzzi, M.R (2006). "Vulnerability analysis of the historical buildings in seismic area by a multilevel approach." *Asian journal of civil engineering (building and housing)*, 7(4), 343-357.

[7] Bustamante, A O (2003). "*Seismic Assessment of Ancient Masonry Structures by Rigid Blocks Limit Analysis*," Phd thesis, Univ. of Minho, Department of Civil Engineering, Guimarães, Portugal.

[8] Giuffrè, A (1993). "*Safety and conservation of historical centres*." Bari: Editori Laterza. (In Italian)

[9] *Instruction for seismic rehabilitation of existing unreinforced masonry buildings (ISRM-85)*, Iranian office of collection and development of national building code, 1st ed., 2006. (In Persian)

[10] *Iranian code of practice for seismic resistance design of buildings (Standard No.2800-84)*, Building and housing research center, 3rd ed., 2005. (In Persian)

[11] *Iranian national building code, part 6: Loading (INBC-06)*, Iranian office of collection and development of national building code, 1996.(In Persian)

[12] Lourenco, P B (2005). "Assessment, diagnosis and strengthening of Outeiro Church, Portugal." *Construction and Building Materials*, 19(2005), 634–645.

[13] *O.P.C.M. 3431/05 09/05/2005, Ulteriori modifiche ed integrazioni all'OPCM 3274/03,* 2005. (In Italian)

[14] Pashanejati, S R (2008). "Seismic assessment of strengthening methods of masonry construction by simplified kinematic limit analysis," Msc Thesis, Technical Univ. of Catalonia, School of Civil Engineering, Barcelona, Spain.

[15] Valluzzi, M R, Cardani, G, Binda, L, and Modena, C (2004). "Seismic vulnerability methods for masonry buildings in historical centres: validation and application for prediction analysis and intervention proposals," in *13th World Conference on Earthquake Engineering, Vancouver, B.C, Canada, August 1-6, 2004, Paper No. 2765.*

[16] Yassavoli, J (2001). "*The Fabulous land of Iran*." 1st ed., Yassavoli Publication. Tehran, Iran.